CHG 3314

HEAT TRANSFER OPERATIONS

FINAL EXAMINATION

DATE: Wednesday, August 11, 2004, 9:30 AM

DURATION: 3 hours

PROFESSOR: Dr. B. Kruczek

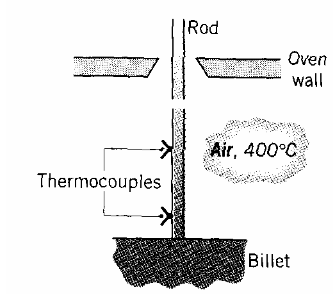
1) Open textbook / class notes examination
2) The examination consists of two parts:
   PART A (40%) – Attempt 2 questions out of 3, each worth 20 marks.
   PART B (60%) – Attempt 2 questions out of 3, each worth 30 marks.
3) State clearly all assumptions.
4) It is strongly recommended to describe in words the outline of your solution.

Good luck!!!

Enjoy the rest of summer

Part A – 40% Attempt 2 of the following 3 questions. Each question is worth 20 marks.

A1. A long rod passes through the opening in an oven having an air temperature of 400°C and is pressed firmly onto the surface of a billet. Thermocouples imbedded in the rod at locations 25 and 120 mm from the billet register temperatures of 325 and 375°C, respectively. What is the temperature of the billet?



A.2 A cylindrical heating element (L = 0.2 m, D = 0.02 m), whose surface is maintained at a constant temperature T_s, is to be placed in the room in which air is at temperature T_e ($T_e < T_s$). The heating element can be mounted vertically, or horizontally. When placed vertically, the Rayleigh number is 5 x 10^8. Neglecting the end and radiation effects, determine the ratio of heat transfer rates in the vertical and horizontal arrangements. Use the following properties of air, Pr = 0.69, k = 0.0290 W/m K.

How would inclusion of the radiative heat transfer from the element affect the ratio calculated above?

A3. Fluid A, available at 10°C is to be heated in a one-shell-pass four-tube-pass exchanger, heat using fluid B available at 180°C. When the mass flow rates of fluids A and B are m_A and m_B, the respective outlet temperatures are, $T_{A,out}$ = 100°C and $T_{B,out}$ = 125°C. To increase $T_{A,out}$ it is proposed to double the mass flow rate of fluid B ($2m_B$) while keeping the mass flow rate of fluid A unchanged. If as a result of doubling the mass flow rate of fluid B the overall heat transfer coefficient (U) in the exchanger increases by 20%, what is the new outlet temperature of fluid A.

Part B – 60% Attempt 2 of the following 3 questions. Each question is worth 30 marks.

B1. Uniform volumetric heating ($\dot{Q}_v'''$) within a solid stainless steel tube is induced by an electrical current and heat is transferred by convection to air flowing through the tube. The tube wall has inner and outer radii of r_1 = 25 mm and r_2 = 35 mm, a thermal conductivity of k = 15 W/m K, and a maximum allowable temperature of 1400 K. Assuming the outer surface to be perfectly insulated and the air flow inside the tube to be characterized by a temperature and convection coefficient of T_e = 400 K and h_i = 100 W/m^2 K, determine the maximum allowable $\dot{Q}_v'''$. Considering that $\dot{Q}_v''' = (R_e I^2)/(\pi r_2^2 - \pi r_1^2)$, where I is the electrical current in [A] and R_e is the electrical resistance per unit length of tube in [Ω/m], determine the maximum current that could be passed through the tube if R_e = 0.7 Ω/m.

B2. A new process for treatment of a special material is to be evaluated. The material, a sphere of radius 5 mm is initially in equilibrium at 400°C in a furnace. It is suddenly removed from the furnace and subjected to a two stem cooling process.

Step 1: Cooling in quiescent air at 20°C for a period of time t_a until the center temperature reaches a critical value $T_a(0,t_a)$ = 335°C. The surface of the sphere has very low emittance so that the radiation from the sphere may be neglected.

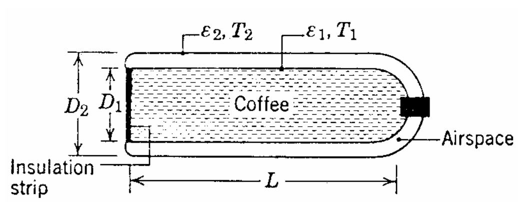
After the sphere has reached this critical temperature, the second step is initiated.

Step 2: Cooling in a well stirred water bath at 20°C, with a convection heat transfer coefficient of 6000 W/m^2 K.

a) Calculate the time t_a required for step 1 of the cooling process to be completed.
b) Calculate the time t_w required during step 2 of the process for the center of the sphere to cool from 335°C to 50°C.

Data for the material: ρ = 3000 kg/m^3, k = 20 W/m K, c_p = 1000 J/kg K

B3. Hot coffee is contained in a cylindrical thermos bottle that is of length L = 0.25 m. The coffee container consists of a glass flask of diameter D_1 = 0.06 m, separated from an aluminium housing of diameter D_2 = 0.07 m by air at atmospheric pressure. The emmisivities of the outer surface of the flask and the inner surface of the housing are ε_1 = 0.30 and ε_2 = 0.40, respectively. Neglecting the end effects, if the respective surface temperatures are T_1 = 75°C and T_2 = 35°C, what is the rate heat loss from the coffee? If the space between the flask and the aluminium housing were to be filled with insulation, what should be the thermal conductivity of the insulation for the rate of heat loss from the coffee to be the same as the one calculated above?



Appendix 1

Table A.7 Gases[a]: Thermal properties

Gas	T K	k W/m K	ρ^b kg/m^3	c_p J/kg K	$\mu \times 10^{6\,c}$ kg/m s	$\nu \times 10^{6\,c}$ m^2/s	Pr
Air	150	0.0158	2.355	1017	10.64	4.52	0.69
(82 K BP)	200	0.0197	1.767	1009	13.59	7.69	0.69
	250	0.0235	1.413	1009	16.14	11.42	0.69
	260	0.0242	1.360	1009	16.63	12.23	0.69
	270	0.0249	1.311	1009	17.12	13.06	0.69
	280	0.0255	1.265	1008	17.60	13.91	0.69
	290	0.0261	1.220	1007	18.02	14.77	0.69
	300	0.0267	1.177	1005	18.43	15.66	0.69
	310	0.0274	1.141	1005	18.87	16.54	0.69
	320	0.0281	1.106	1006	19.29	17.44	0.69
	330	0.0287	1.073	1006	19.71	18.37	0.69
	340	0.0294	1.042	1007	20.13	19.32	0.69
	350	0.0300	1.012	1007	20.54	20.30	0.69
	360	0.0306	0.983	1007	20.94	21.30	0.69
	370	0.0313	0.956	1008	21.34	22.32	0.69
	380	0.0319	0.931	1008	21.75	23.36	0.69
	390	0.0325	0.906	1009	22.12	24.42	0.69
	400	0.0331	0.883	1009	22.52	25.50	0.69
	500	0.0389	0.706	1017	26.33	37.30	0.69
	600	0.0447	0.589	1038	29.74	50.50	0.69
	700	0.0503	0.507	1065	33.03	65.15	0.70
	800	0.0559	0.442	1089	35.89	81.20	0.70
	900	0.0616	0.392	1111	38.65	98.60	0.70
	1000	0.0672	0.354	1130	41.52	117.3	0.70
	1500	0.0926	0.235	1202	53.82	229.0	0.70
	2000	0.1149	0.176	1244	64.77	368.0	0.70